Applications of informatics in veterinary medicine

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This study used the peer-reviewed biomedical literature to define the veterinary informatics knowledgebase and associated subspecialties, and assesses the level of activity in the field over the thirty-year period from 1966 through 1995. Grateful Med was used to search the MEDLINE bibliographic database for articles that shared one or more Medical Subject Headings (MeSH) keywords from the veterinary and medical informatics subject headings. Each of ninety-five MeSH medical informatics terms was assigned to one of twelve veterinary informatics subspecialties. The number of articles retrieved by each MeSH keyword and subspecialty was calculated. A total of 611 articles were retrieved, representing the contributions of 1,338 authors published in 153 journals. The field experienced slow growth over the twenty-year period from 1966 through 1985. In the following decade, the cumulative number of veterinary informatics articles almost tripled and the percentage of veterinary-related articles that included an informatics component increased almost two-and-one-half fold. Despite this recent growth, the number of veterinary-related articles with an informatics component has never exceeded 1% of either the veterinary or medical informatics literature over the past thirty years, and representation of veterinary subspecialties in the literature varied widely.

INTRODUCTION

Medical informatics is the discipline concerned with the theoretical foundations and application of information science, engineering, and computer technology in medical teaching, research, and practice. Although computers and information science have been incorporated into all facets of the veterinary profession, veterinary informatics has received little attention as a recognizable discipline. In 1991, Talbot [1] defined the field of veterinary informatics, including an overview of the many applications of medical informatics in the veterinary profession. A number of subspecialties of veterinary informatics were described with examples of their contributions to veterinary medicine. These areas have been represented in the American Academy of Veterinary Informatics's (AAVI) topical organization of the discipline*, which closely followed medical informatics subspecialties defined by Shortliffe et al. [2].

The purpose of the study was to enhance understanding of the field through the definition and systematic study of the veterinary informatics knowledgebase over the thirty-year period from 1966 through 1995.

METHODS

Defining the veterinary informatics knowledgebase

The disciplines of veterinary medicine and medical informatics, and their respective specialties are represented in the National Library of Medicine's (NLM) MEDLINE bibliographic database. MEDLINE includes more than nine million references to peer-reviewed articles published in 3,900 biomedical journals in the United States and seventy other countries dating back to 1966. MEDLINE has worldwide coverage, but 88% of the citations are to English-language sources and 76% have English abstracts.

* The American Academy of Veterinary Informatics (AAVI) Web site may be viewed at http://netvet.wustl.edu/aavi.htm.

Each bibliographic citation has fifteen fields including author or authors, title, journal reference, author abstract (when available), and list of relevant Medical Subject Headings (MeSH). MeSH is NLM's controlled vocabulary consisting of a set of subject headings, or terms, arranged in a hierarchical structure. Headings at the most general level of the hierarchical structure include, for example, ''Biological Sciences,'' ''Diseases,'' and ''Information Science.'' At the more detailed level are terms such as ''Pathology, Veterinary''; ''Hip Dysplasia, Canine''; and ''Medical Records Systems, Computerized.'' There are more than 18,000 main headings in the primary structure of MeSH.

Because MeSH terms are systematically applied to every reference included in the MEDLINE database, a search using appropriate MeSH terms should generate the bulk of the relevant references that form the veterinary informatics knowledgebase. Furthermore, by assigning MeSH terms and the corresponding articles retrieved to appropriate categories, better defining veterinary informatics subspecialties should be possible.

MeSH medical informatics and veterinary subheadings

The MeSH medical informatics subject heading includes ninety-five distinct terms that are listed in Table 1 in association with the AAVI subspecialties to which they were assigned. The MeSH veterinary subject heading includes fifteen distinct terms:

1. Veterinary (subheading)
2. Veterinary Assistants (= Animal Technicians)
3. Veterinary Clinics (= Hospitals, Animal)
4. Veterinary Medicine
5. Pathology, Veterinary
6. Surgery, Veterinary
7. Veterinary Service, Military
8. Abortion, Veterinary
9. Brucellosis, Bovine
10. Anatomy, Veterinary (the field or occupation)
11. Education, Veterinary
12. Hospitals, Veterinary (= Hospitals, Animal)
13. Legislation, Veterinary
14. Schools, Veterinary
15. Venereal Tumors, Veterinary

The term ''Veterinary'' is also used as a subheading for a variety of specific diseases or techniques. This subheading has the effect of expanding the number of veterinary-related articles retrieved.

MEDLINE search

NLM's Grateful Med was used to perform three MEDLINE searches. The first two searches retrieved all articles that included one or more MeSH terms from the medical informatics or veterinary subject heading categories, respectively, over the thirty-year period from January 1, 1966, through December 31, 1995. Where appropriate, broad MeSH terms were exploded to assure inclusion of all terms considered to be a subset of the broader term. The number of articles retrieved yearly for each subject heading was recorded. Duplicate references were omitted from the tally.

A third, more restrictive search was performed to retrieve articles that included one or more MeSH terms from both the medical informatics and veterinary subject heading categories. This combined search strategy retrieved only veterinary-related medical informatics articles. Retrieved references were downloaded and imported into EndNote Plus 2.1 for further analysis and assignment to appropriate veterinary informatics subspecialties.

Analysis and assignment of references to veterinary informatics subspecialties

In order to categorize veterinary informatics references, all ninety-five medical informatics terms in MeSH were assigned to subspecialties, using the earlier AAVI scheme as a guide. The AAVI subspecialties are: (1) historical perspectives; (2) medical record systems; (3) hospital information systems; (4) laboratory information systems; (4) pharmacy; (5) radiology/imaging; (6) patient monitoring; (7) practice management; (8) information and bibliographical retrieval; (9) decision support; (10) clinical research; (11) education; (12) epidemiology—simulations, biomedical statistics, production/performance assessment; and (13) systems evaluation and validation.

In cases where the content of retrieved articles was highly complementary, corresponding AAVI categories were combined. Some MeSH terms are intended to describe the tools of informatics rather than their purpose. These were included under a new ''Hardware and Programming'' category. However, most of the corresponding articles included MeSH informatics terms assigned to other categories as well. For some AAVI categories assigning a corresponding MeSH term was not possible. The resulting list of veterinary informatics subspecialties appears in Table 1.

The total number of veterinary medical informatics articles retrieved by each MeSH term and for each veterinary informatics subspecialty was calculated. Duplicate references were excluded. Descriptive statistics were calculated to assess the relative level of activity, based on number of publications, in each subspecialty. The total number of veterinary informatics articles published per year was also compared with that for medical informatics in general.

RESULTS

A total of 611 veterinary informatics articles were retrieved by the combined search strategy, representing the contributions of 1,338 authors published in 153

Table 1
Veterinary informatics subspecialties (ranked by number of references retrieved), the MeSH terms assigned to each, the number of veterinary-related articles (hits) retrieved by each MeSH term, and the total number of articles retrieved for each subspecialty

Veterinary informatics subspecialties (adapted from AAVI)* (number of articles retrieved in parentheses	**MeSH medical informatics terms†** (number of articles retrieved in parentheses)
Information and bibliographical retrieval (total = 135) Computer-based systems for the storage, retrieval, and sharing of biomedical information locally or over networks [36, 37].	Information Systems (88); Databases, Factual (30); Online Systems (7); Computer Communication Networks (6); Databases, Bibliographic (5); MEDLARS (3); Database Management Systems (2); Information Storage and Retrieval (2); MEDLINE (2); Management Information Systems (1); Grateful Med (0); Community Networks (0); Integrated Advanced Information Management Systems (0); Local Area Networks (0); National Practitioner Data Bank (0); Unified Medical Language System (0)
Decision support (total = 47) Computer-based systems that assist practitioners in making decisions about patient care [38, 39].	Diagnosis, Computer-Assisted (41); Expert Systems (5); Decision Making, Computer-Assisted (1); Decision Support Systems, Management (1); Therapy, Computer-Assisted (1); Drug Therapy, Computer-Assisted (0); Radiotherapy, Computer Assisted (0)
Radiology/imaging (total = 40) A computer-based information system for the acquisition and analysis of medical images, including X-ray imaging, computed tomography, echosonography, and magnetic resonance imaging [40].	Image Processing, Computer-Assisted (37); Image Enhancement (4); Radiographic Image Enhancement (3); Image Interpretation, Computer-Assisted (2); Radiographic Image Interpretation (0); Radiology Information Systems (0); Radiography, Dual-Energy Scanned (0)
Clinical research/epidemiology (total = 40) The use of computers to assist in the collection and analysis of animal health/production data from individual patients or populations that can be used to improve the diagnosis, management, control, and prevention of disease [41, 42].	Data Interpretation, Statistical (21); Decision Support Techniques (9); Decision Trees (6); Mathematical Computing (4); Decision Theory (1); Numerical Analysis (1)
Education (computer-assisted instruction, CAI) (total = 21) The application of computer technology to education to assist in the delivery of factual knowledge, of problem-solving experiences, and for student assessment [43, 44].	Computer-Assisted Instruction (16); Computer Literacy (2); Computer User Training (1); Word Processing (1); Programmed Instruction (3)
Medical record systems (total = 12) Computer-based information systems for the capture and manipulation of patient data for the purpose of facilitating patient care, meeting legal and financial requirements, and aiding clinical research [45].	Nomenclature (12); Medical Informatics (1); Medical Records Systems, Computerized (0)
Patient monitoring (total = 8) A computer-based system for repeated or continuous observation or measurement of the patient, physiological parameters, and function of life support equipment for the purpose of guiding and assessing therapeutic management [46].	Monitoring, Physiologic (8)
Hospital information/practice management systems (total = 5) Computer-based information systems that integrate both medical and administrative functions of medical facilities and services including patient information from all contributing services, scheduling and staffing, inventory, accounting, and other fiscal functions [47–49].	Office Automation (5); Ambulatory Care Information Systems (0); Hospital Information Systems (0); Operating Room Information Systems (0); Personnel Staffing and Scheduling Information (0); Reminder Systems (0)
Laboratory information systems (total = 1) Computer-based information system that support laboratory functions for collecting, verifying, and reporting test results [50]	Clinical Laboratory Information Systems (1)
Pharmacy systems (total = 0) Computer-based information systems for the management of medical information systems related to drugs and to the use of drugs in patient care [51].	Clinical Pharmacy Information Systems (0)
Systems evaluation and validation (total = 0) Issues related to the design, development, and evaluation of medical information systems [52].	No applicable MeSH terms
Hardware and programming (total = 434) Some MeSH terms are intended to describe the tools of informatics rather than their purpose.	Computers (252); Software (124); Microcomputers (74); Computer Simulation (66); Automatic Data processing (32); Algorithms (18); Punched-Card Systems (12); Signal Processing, Computer-Assisted (8); Minicomputers (6); Computer Systems (4); Data Display (4); Artificial Intelligence (3); Computer Graphics (3); Analog-Digital Conversion (2); Computers, Analog (2); Database Management Systems (2); Software Design (2); Compact Disks (1); Computer Terminals (1); Neural Networks (Computer) (1); User-Computer Interface (1); Computer Peripherals (0); Computer Storage Devices (0); Optical Storage Devices (0); CD-I (0); CD-ROM (0); Computers, Hybrid (0); Computers, Mainframe (0); Fuzzy Logic (0); Natural Language Processing (0); Robotics (0); Computer-Aided Design (0); Programming Languages (0); Software Validation (0); Video Games (0)

* References refer to sources used to define each subspecialty.
† MeSH terms are ranked by number of hits. Duplicate articles were not counted.

Figure 1
Yearly and cumulative number of veterinary informatics published each year over the thirty-year period from January 1, 1966, through December 31, 1995

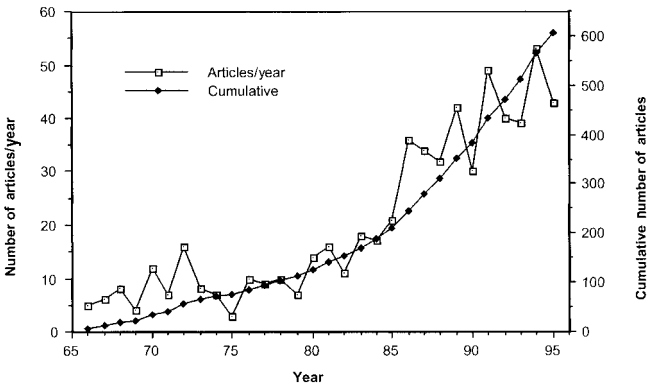
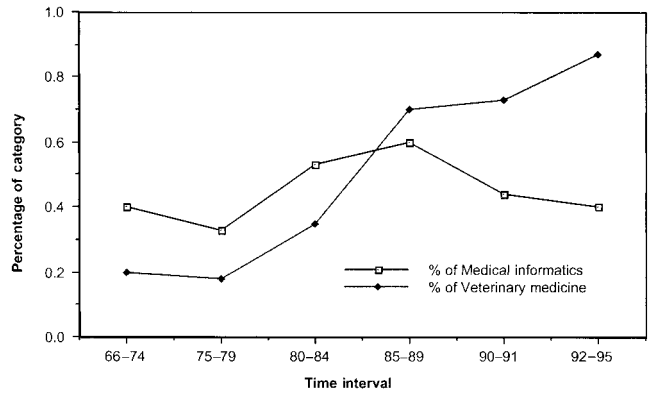


Figure 2
Percentage of all medical informatics and veterinary-related articles that included a veterinary informatics component over the thirty-year period from January 1, 1966, through December 31, 1995



journals. Figure 1 depicts the number of veterinary informatics articles retrieved by the combined search strategy on a yearly basis and cumulatively over the thirty-year study period. Based on the number of veterinary informatics articles published per year, the field experienced slow growth over the twenty-year period from 1966 through 1985. In the following decade, the cumulative number of veterinary informatics articles almost tripled.

Figure 2 depicts the percentage of all medical informatics and veterinary-related articles that included a veterinary informatics component (combined search strategy) over the thirty-year period. The time intervals reflect the way in which MEDLINE references are grouped. Although veterinary informatics articles never exceeded 1% of either category, the percentage of veterinary-related articles that were of a veterinary informatics nature increased almost two-and-one-half fold over the ten-year period from 1985 through 1995. The percentage of medical informatics articles of a veterinary nature remained relatively stable over the thirty-year time period.

The identity and definition of each veterinary informatics subspecialty, the MeSH terms assigned to each, and the number of articles retrieved are summarized and ranked in Table 1. Some subspecialties, such as information and bibliographic retrieval, were well represented in the veterinary literature. Others, such as laboratory and pharmacy information systems, and systems evaluation and validation, were not represented in the veterinary literature. There was a tendency for the number of articles retrieved to be directly related to the number of corresponding MeSH terms assigned to each subspecialty. Exceptions occurred, however. Only five articles were retrieved by the six MeSH terms assigned to the hospital information/practice management subspecialty compared with eight articles retrieved by the single MeSH term assigned to the patient monitoring subspecialty.

DISCUSSION

Appropriateness of MeSH for documenting activity in the field

Veterinary clinicians and researchers both use and publish in a wide variety of biomedical publications. While fewer than seventy journal titles are listed as ''Veterinary Medicine'' in the subject listing of *List of Journals Indexed in Index Medicus* (1998), MEDLINE is often the database of choice for small animal clinical specialists such as oncologists, dentists, and dermatologists. The importance of MEDLINE to veterinary medicine is also evident in the 1996/97 survey of the thirty veterinary libraries in the United States and Canada [3], which shows searches conducted in MEDLINE nearly equal that of CAB International, a database that includes *Index Veterinarius* and *Veterinary Bulletin.*

Although coverage of the veterinary literature by MEDLINE is less comprehensive than that of the human medical literature, MEDLINE's controlled MeSH vocabulary is superior to keyword-based, free-text searching of other veterinary-related bibliographic databases for informatics articles. The MeSH-based search strategy provides a rapid, systematic, and reproducible way of finding articles at the interface of veterinary medicine and medical informatics. However, several peculiarities in the indexing system are apparent. For example, the finding that the Systematized Nomenclature of Medicine (SNOMED), used to record diagnoses and procedures in both human and veterinary medicine, is not a MeSH term and that nomenclature is not included under the medical informatics

heading probably does reduce the number of articles retrieved. However, the MeSH medical informatics vocabulary is sufficiently rich to permit most veterinary informatics articles to be retrieved, as long as the appropriate keywords are assigned by the indexers.

This study provided a test of the appropriateness of the earlier AAVI categories for organizing the veterinary informatics knowledgebase. The task of assigning most MeSH terms to a corresponding AAVI subspecialty was relatively easy, even though the MeSH medical informatics hierarchy differed considerably from the functional categories developed by the AAVI. There were exceptions, however. For example, ''Image Interpretation, Computer-Assisted'' appeared in the MeSH tree under ''Diagnosis, Computer-Assisted.'' However, it could logically be considered to be part of the veterinary ''Radiology/Imaging'' subspecialty. Wherever such apparent conflicts occurred, the MeSH term was assigned to a veterinary informatics subspecialty based on the kinds of articles retrieved. For example, the single article classified as ''Word Processing'' [4] really described a case-authoring tool for computer-assisted instruction. This approach was also necessitated by the fact that some MeSH terms appeared at multiple sites in the MeSH tree.

In some cases, the retrieved articles covered such a broad range as to prohibit reasonable assignment of the MeSH term to a particular veterinary informatics subspecialty. For example, the MeSH term ''Computer Systems'' retrieved four articles, one each in practice management, regulatory information systems, computer-assisted diagnosis, and computer-assisted instruction. Similarly, the MeSH term ''Computers'' retrieved 252 references and ''Microcomputers'' retrieved seventy-four covering the gamut of veterinary informatics. In the interest of completeness, these terms were represented in the hardware and programming subspecialty, but their placement did not necessarily represent the nature of the articles retrieved.

Representativeness of findings for activity in the field

Clearly, some areas, such as nomenclature and information systems in general, are well represented in the literature. On the other hand, the MeSH term ''Medical Records Systems, Computerized'' retrieved only three articles, despite a tremendous amount of experimentation in all university veterinary teaching hospitals. Similarly, ''Computer-Assisted Instruction'' retrieved only sixteen articles despite the fact that considerable faculty effort is being devoted to this area at all veterinary colleges. It is unfortunate that the experiences of veterinary academicians in such an important area are not being reported in a systematic and generalized way.

Informatics contributions to teaching, research, and practice

The veterinary informatics knowledgebase generated during the course of this study provided insight into the development of the field and its contributions to veterinary medicine. Veterinary computing and information technology have come a long way since the days when a punched-card system was used to study medical operations at a major U.S. veterinary teaching hospital [5] and practitioners reported on veterinary applications for word processing on personal computers [6, 7]. The educational use of computers has been an area of constant experimentation and development [8–18]. Practice management packages have been in use for more than a decade. Early attempts [19] to establish performance standards for certifying practice management software did not catch on. Consequently, continued development and testing of this software has been entirely in the private sector.

In addition to practice management, practitioners can use their computers to search remote online bibliographic databases [20, 21], obtain expert consultation on diagnostic and treatment options [22–24], and participate in online discussions of interesting or difficult cases with colleagues around the world [25]. However, these resources are still underutilized by practitioners [26–28], who primarily use computing technology for word processing and practice management [29]. This type of usage should change rapidly, however, as recent cohorts of highly computer-literate veterinary graduates [30, 31] become established in the profession.

Besides bibliographic databases, other computerized animal health or disease databases have been developed. Several reports have argued that a standard coding system, such as SNOMED International, is crucial for the exchange of information between these databases [32–34]. Online (Internet-based) information sharing and collaboration are having tremendous positive effects on animal disease surveillance and research [35]. The recent explosion of information on bovine spongiform encephalopathy (BSE or ''Mad Cow Disease'') on e-mail discussion lists and the Web provides evidence of these effects.

CONCLUSIONS

This paper is the first to define veterinary informatics subspecialties formally based on documented activity in the field. Few of the 1,338 authors contributing to the 611 articles retrieved in this study would consider themselves to be ''veterinary informaticians.'' As the field grows, however, there may be a need for a cadre of veterinary informatics specialists who continually monitor the field, contribute to its advancement, and

explore new ways to use computing and information science in veterinary medicine.

Medical informatics concepts and techniques have been incorporated into all aspects of veterinary medicine with an impact beyond simply improving the quality of patient care. The impact can be global, as in the case of Internet-based distance learning and information exchange. The veterinary informatics knowledgebase, as revealed by this study, is more than thirty years old and appears to be growing at a higher rate than the overall veterinary medical knowledgebase. The magnitude of this growth must be interpreted with caution, as there has been a concomitant proliferation of MeSH terms over the thirty-year study period as well, increasing the likelihood of article retrieval. Regardless of its absolute level of growth, veterinary informatics represents only a small portion of the overall level of veterinary research activity.

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